EXCITATION AND DETECTION TECHNIQUES FOR MILLIMETER WAVE TRANSITIONS

Third Quarterly Progress Report

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Object: The object of this contract is to investigate the excitation and detection techniques for molecular millimeter wave transitions which can be used to develop a frequency standard operating in the region of 1 millimeter.

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Orlando, Florida

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PURPOSE

The purpose of this contract is to investigate the excitation and detection techniques for molecular millimeter wave transitions which can be used to develop a frequency standard operating in the region of 1 millimeter. The part of the project concerned with the excitation of molecular transitions is a study of the means of providing a highly stable exciting signal with sufficient power to induce transitions, and an investigation of the resonant structure techniques for exciting the beam. The second part, the study of detection techniques, covers methods of detecting molecular transitions with provisions for using the detected signal for frequency control.

ABSTRACT

The molecular beam apparatus is now undergoing detector tests. An ammonia maser has been put into operation and used for stability tests of phase-locked oscillators. Beam absorption studies are being performed to determine the effect of radiation techniques on the line width of the molecular resonance. A Fabry-Perot interferometer has shown high sensitivity as a millimeter spectrometer.

CONFERENCES ATTENDED

J. J. Gallagher and V. E. Derr attended the Brooklyn Polytechnic Symposium on Optical Masers where several interesting discussions emphasized the importance of laser techniques for far-infrared and submillimeter wave physics.

I. MOLECULAR BEAM APPARATUS

The molecular beam apparatus has been completely assembled and vacuum tests have been performed on the chambers. At present, a vacuum of 10^{-8} mm Hg can be obtained in the detector chamber and the source chambers, whereas the interaction chamber has been evacuated to a pressure of 10^{-7} mm Hg. For optimum operating conditions, these pressures will have to be lowered by a factor of 10. Small leaks have been detected in the interaction chamber, and a new chamber is now being constructed to replace the old chamber. Neither prolonged pumping nor long bakeout periods have been employed as yet.

All components have been constructed for the beam machine. Electrostatic deflectors, C-field plates, buffer plates, and the required millimeter signal components have been assembled. Two ionizers have been constructed for the mass spectrometer detector. One employs an x-ray tube to ionize the beam; the second ionizer is an electron bombardment device, similar to that constructed by Weiss.[1] A third ionizer, an electron bombardment type, but less complicated than the Weiss ionizer, is now being assembled. Tests have begun to determine the effectiveness of these ionizers. A General Electric model 514 partial pressure gas analyzer is also being employed to compare ionizers and to determine the constituents of the background. This analyzer has also served very effectively as a helium leak detector; with the proper slit arrangement, the ionizer might be used to detect the beam.

No conclusive results have been obtained with the beam detectors, but the results of the present tests will be reported in the next quarterly report.

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II. AMMONIA MASER

The ammonia maser described in the second quarterly report was completed. The output power was sufficient to phase lock a klystron and also sufficient for use as a reference for spectral purity tests.

The TE_{011}-mode maser cavity was electroformed with copper and has a loaded Q of 12,000. A 0.096-inch coupling hole is used. A sliding end plunger tunes the cavity approximately 10 mc. The focuser is a quadrupole structure 8 inches long with 1/4-inch-diameter rods on a 5/8-inch-diameter circle. The klystron-grid-type effuser has a diameter of 3/16-inch-diameter. The maser oscillated with source pressures of 1.5 to 5 mm Hg and focuser voltages of 10 to 28 kilovolts.

The maser chamber is presently being used for H_2S maser work. When this work is completed, a semiconfocal interferometer will be tested as an ammonia maser cavity. The interferometer plates are brass of 4.6-inch-diameter. The flat plate has input and output coupling holes and is supported by the K-band waveguide. The curved plate is supported by a 3/4 inch threaded rod, used for tuning. The rod is brought out of the vacuum chamber through a Wilson seal. At the end of the focuser, a liquid-nitrogen-cooled plate with a 3/8-inch hole separates the effuser and focuser chamber from the interferometer.

The purpose of this experiment is to observe maser action at 23870 mc in an interferometer and then, by reducing the coupling irises, to attempt to observe maser action from $\Delta J = 1$ transitions occuring in the infrared. The radiation will result from a rotation-inversion transition of ammonia and will be detected by a Golay cell. Simultaneous application of an inversion frequency will determine the transition undergoing maser action.

III. MILLIMETER SPECTROSCOPY

An additional H_2S line was found during the last quarter. This now provides seven lines for an analysis of the spectrum from which three rotational constants and four distortion constants can be determined. This may not, though, provide the most accurate calculation of constants; it is therefore necessary to combine the data from the three isotopic forms of hydrogen sulfide and to use the force constants obtained from a normal coordinate analysis of the infrared spectrum. A full status report on the millimeter spectroscopy of hydrogen sulfide will be given in the next quarterly report.

IV. HYDROGEN SULFIDE MASER

During the past quarter, a beam maser has been constructed to operate on the $1_{-1} \leftrightarrow 1_1$ transition in H_2S. A semiconfocal interferometer has been placed in the maser chamber and the absorption line of H_2S at 168.7 gc has been observed. Calculations on the state separation for H S have been performed on a computer; with the analysis of Vonbun,[2] the trajectories of the H_2S molecules have been calculated for several initial conditions and for several deflector voltages. The state separator, for which the calculations have been performed, is a four-rod axial electrostatic focuser. The first run on the computer indicated that it should be possible to focus the $J_\tau = 1_1, M_J = \pm 1$ states within a 1-centimeter circle while deflecting the states $J_\tau = 1_1, M_J = 0$ and $J_\tau = 1_{-1}, M_J = 0, \pm 1$ sufficiently to miss the 1-centimeter circle. The deflector has been lengthened to 11 inches for further separation of the states. Subsequent computer runs have shown that, for most initial conditions used, the desired state separation is achieved for a voltage of 24 kv on the deflectors. The calculations showed, however, a large dependence on ϕ_0, the initial azimuthal angle. The use of an eight-pole focuser appears to be more desirable, and such a device is now under construction. The calculations are being adjusted to include the case of eight rods.

The computation of the minimum number of particles required for oscillation shows that with a Q of 40,000, which is being achieved with the interferometer in the maser chamber, sufficient molecules are obtained for oscillation. Otherwise, an array of effusers and focusers, as suggested by Dicke[3] and used by Marcuse,[4] may be necessary. Present experimentation should determine if oscillation will be observable.

V. MILLIMETER COMPONENTS

During the past quarter, the semiconfocal interferometer has been used as a millimeter spectrometer (see Section VIII). The difficulty of using such a high-Q resonator with frequency or phase modulation to increase spectrometer sensitivity has prompted the consideration of installing Stark modulation plates. If frequency or phase modulation is used, recording through the resonance causes such large amplitude changes that observation is difficult and impractical. The Stark modulation will, however, avoid the amplitude change resulting from the interferometer resonance and provide the sensitivity necessary to observe lines considerably weaker than has thus far been possible. Several weak lines of the $\Delta J = \pm 1$ type occur for H_2S in the millimeter region, but no spectrometer sensitive enough to detect them exists.

Several semiconfocal interferometers have been described in previous quarterly reports; however, the field configuration of the plane parallel plate interferometer is required if minimum line width in a millimeter beam machine is to be realized.

During the past quarter, attempts were made to fabricate flat plates for 168 gc using a technique described by Welling and Andresen.[5] A Fosdick automatic drilling machine was programmed to drill approximately 3100 holes on a 2.2-inch-diameter aluminum plate. The holes were 0.0175 inch-in-diameter and 0.035 inch between centers. The plates were machined from a 1/2-inch-thick aluminum disc 2 3/4-inch-diameter. The 2.2-inch-diameter was reduced to 0.025 inch thickness for drilling. The plates were then lapped and polished at 0.018 inch thickness. The transmission of the plates was tested but the loss was greater than 36 db at 168 gc. An attempt was made to improve the transmission by reducing the thickness to 0.015 inch, but the plates buckled. They had been fitted with a support for drilling and lapping.

A second method of fabricating plates (flat and curved) is now being tested. In this, the plates were cut from rexolite and hand polished. The flat plates were checked optically and are flat to 0.000010 inch. Several skin depths of silver were deposited on the plates by vacuum-deposition techniques, and the hole pattern was made by photo etching. These plates will be tested during the coming quarter. Work has been started on tuning mechanisms.

A superconducting magnet has been obtained to provide the field for a Putley photoconductive detector. The crystal for the detector is being grown, and the detector will be assembled when the crystal preparation is finished. The magnet provides a field of 6,000 gauss for a current of 19.30 amperes. The coil may be safely operated up to 9,300 gauss with a rated 0.311 kilogauss per ampere. Provision is made for operation in the presistent mode.

A carbon resistor detector is also being assembled and will operate in the same cryogenic arrangement as the Putley detector.

VI. SPECTRAL PURITY OF RF SOURCES

The ammonia maser was used as a reference for measuring the spectral purity of various oscillator and RF multiplier outputs. The comparison was made at the maser frequency as shown in Figure 1. The RF multiplier outputs are at 100 mc and 120 mc. The pill varactor diode is used to generate the 239th harmonic of 100 mc or the 199th harmonic of 120 mc. The 10-mc offset for phase locking puts the klystron output at 23890 mc for either input. The klystron and maser outputs are mixed and the beat (approximately 20 mc) is amplified and observed with a Marconi OA1094 spectrum analyzer. The 10-mc input to the phase lock is crystal controlled but does not contribute any measurable instability to the klystron output because it is not multiplied. The ability of the phase-locked klystron to lock to the multiplied output of a crystal oscillator has been checked by observing the IF of the phase lock on the spectrum analyzer.[6] These tests showed the sidebands on the IF phase lock to be at least 40 db below the carrier. Therefore, the observed spectrum in this setup will be the spectrum of the oscillator and multiplier chain multiplied to 23890 mc. The sweep of the spectrum analyzer was calibrated at 20 mc using the Rohde and Schwarz XUA frequency synthesizer.

The oscillators tested were a James Knight JKFS1100T frequency standard, a General Radio 1113A, a General Radio 1101B, the Rohde and Schwarz XUA, and a Hewlett-Packard 608C signal generator. The multipliers used were a laboratory-built multiplier with 5- or 10-mc input and 120-mc output; and a General Radio 1112A multiplier with inputs of 0.1 or 5 mc and outputs of 1, 10, and 100 mc. The laboratory-built multipliers use diode multipliers and Class A amplifiers. The GR multiplier outputs are from phase-locked oscillators. The 100-mc output of the GR multiplier was amplified to drive the pill varactor. Various combinations of multipliers and oscillators were tested, as described in the following paragraphs.

A. JAMES KNIGHT FS1100T (1-MC OUTPUT)

With the output fed directly to the laboratory-built 1-100 mc multiplier, the spectrum was not good enough to phase lock the klystron. When the 1-mc output was multiplied to 10 mc in the GR multiplier (phase-locked oscillator output), the spectrum could be observed as described above and the results were the same using any of the three multipliers. The spectrum was a broad noise band with a 3-db width of 2.5 kc and a 20-db width of about 8 kc. The spectrum did not repeat on successive sweeps of the spectrum analyzer and an actual carrier frequency was not detected.

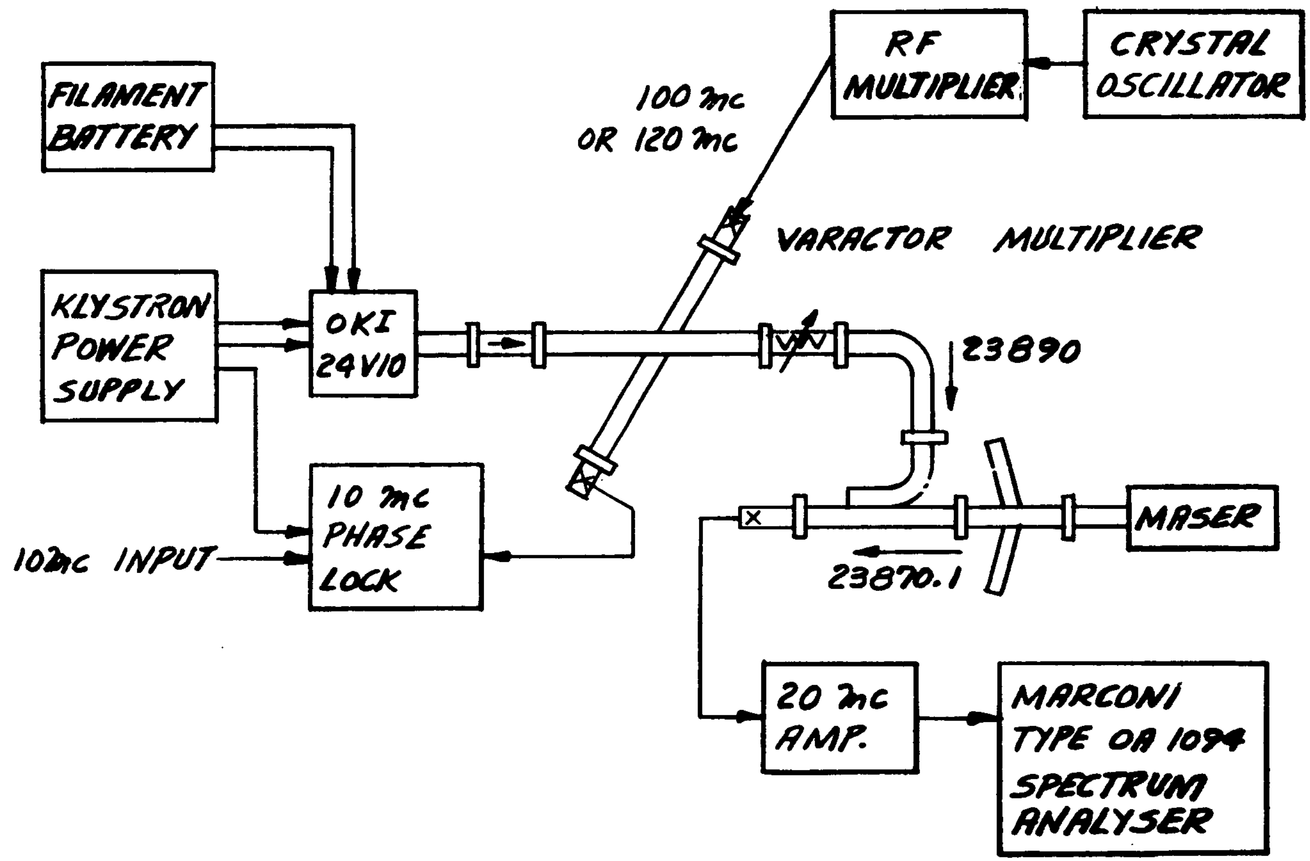

Figure 1. Comparison of RF Sources with Ammonia Maser

B. JAMES KNIGHT FS1100T (1-MC OUTPUT WITH A CRYSTAL FILTER IN SERIES WITH THE OUTPUT)

With the 1-mc output multiplied to 10 mc, the spectrum was observed with the three multipliers and the results were the same. The noise spectrum width was greatly reduced with the addition of the filter. The 3-db bandwidth was 50 cps and the 20-db width was about 400 cps. No 60-cps sidebands were observed. The carrier repeated on successive spectrum analyzer sweeps. When the 1-mc was multiplied by the laboratory-built multiplier without using the 10-mc GR multiplier output, the klystron would not remain in lock satisfactorily.

C. GENERAL RADIO 1113A (5-MC OUTPUT)

This spectrum had 60-cps sidebands but did not have the noise band of the James Knight. When using the 10-mc output of the GR multiplier, the spectrum was the same using any of the three multipliers. The first 60-cps sidebands were 6 db below the carrier. The sidebands were down 20 db 360 cps from the carrier and 30 db down 600 cps from the carrier. When the 5-mc output was used to drive either laboratory-built multiplier, the first sidebands were 10 db below the carrier, the next sidebands were 20 db below, and the sidebands were 30 db down 240 cps from the carrier. There apparently was some higher-frequency components which the klystron was not locking to, for it did not lock properly. The difficulty was not definitely established.

D. GENERAL RADIO 1101B OSCILLATOR (100-KC OUTPUT)

This spectrum showed 60-cps sidebands as well as a noise band. The 3 db width was about 1200 cps.

E. ROHDE AND SCHWARZ XUA FREQUENCY SYNTHESIZER (10-MC OUTPUT)

The spectral purity was so poor that the klystron could not be phase locked.

F. HEWLETT-PACKARD 608C SIGNAL GENERATOR (10-MC OUTPUT)

This oscillator was tested because a HP608C was used as the fundamental oscillator for the LiF beam experiment at Harvard.[6] The 30 db spectrum width was greater than 30 kc. The carrier frequency could not be detected. Unless the HP608C at Harvard was significantly better than the one tested, the measured line width for the LiF resonance experiment could be accounted for by the poor spectrum. (The LiF frequency at 88 gc required a X4 multiplier from K band). It is interesting to note that the phase lock worked very well with this spectrum, indicating the sidebands are due to low-frequency-modulation components.

The measurements indicate that in order to obtain a millimeter signal of sufficient spectral purity for molecular beam excitation, the crystal oscillator outputs will have to be improved. Since the multipliers used did not exhibit 60-cps sidebands with the James Knight oscillator, and since they showed only 60-cps sidebands and no broad noise band with the General Radio oscillator, the multiplier noise and incidental fm is not the limiting factor.

Crystal filters will be used in an attempt to improve the spectrum of the available oscillators. The 1-mc crystal filter used with the James Knight oscillator was a series-resonant crystal in series with a 50-ohm load. A lower load impedance would improve the Q of the filter and improve the spectrum if the additional amplification did not introduce excessive noise. High frequency oscillators will be tested. By reducing the multiplying factor, the spectrum should be improved.

VII. BEAM ABSORPTION STUDIES

The small beam system described in the first quarterly report has been used to observe the 168-gc H_2S absorption line. The gas is passed between a pair of horns and lenses and trapped with a liquid-nitrogen trap just after it passes the horns. The 1/2 by 2 1/2 inch crinkled-foil effuser was masked to an active area of 1/2 by 1 inch. The line was observed with a video detector and lock-in amplifier with a source pressure of 0.4 mm Hg and a chamber background pressure of 5 by 10^{-5} mm Hg. The line could be observed on an oscilloscope trace with a source pressure of 2.5 mm Hg. The line width between points of maximum derivative was 210 kc. The nuclear hyperfine components have not as yet been observed; 6-kc frequency modulation has been used for detection. Investigations are now being made using lower frequency modulation (and therefore greater crystal noise) and other millimeter wave structures.

VIII. MILLIMETER SPECTROMETER USING A FABRY-PEROT INTERFEROMETER*

To achieve high signal-to-noise ratios in the millimeter region where low power is available, a high-sensitivity spectrometer has been designed using a semiconfocal-type Fabry-Perot interferometer. Early investigations of Fabry-Perot interferometers in the microwave region began primarily with the work of Culshaw[7, 8]. Marcuse[9] has used a confocal resonator in an HCN maser operating at 88.6 gc. In the work discussed in this paper, hydrogen sulphide gas was used to test the spectrometer.

The hydrogen sulphide molecule was originally investigated in the millimeter region by Burrus and Gordy[10] who found lines at 168.7 gc and 216.7 gc corresponding to the $1_{-1} \rightarrow 1_1$ and $2_0 \rightarrow 2_2$ transitions, respectively. More recently, Burrus and Trambarullo[11] have observed a line at 300.5 gc. Hydrogen sulphide was chosen to test the interferometer because of the strong transitions given above arising from H_2S^{32} with S^{32} in its natural concentration of 95.1 percent, and the weaker transitions arising from the isotopic species, H_2S^{33} and H_2S^{34} with S^{33} and S^{34}, in their natural concentrations of 0.74 and 4.2 percent, respectively.

The resonance of a cavity is affected when an absorbing gas is introduced into the cavity. The quality factor Q is decreased due to the increased losses. Thus, microwave absorption can be detected by the change in a transmitted or reflected wave in the cavity. For high sensitivity, the Q value should be large; however, it is limited to a value such that the width of the cavity resonance is wide enough to display the entire line, and possibly the fine structure if present.

Using a high-Q cavity as an absorption spectrometer, very long effective path lengths can be achieved from the relation $Q\lambda/2\pi$, which gives the equivalent absorption path length in free space.[11]

A. EXPERIMENTAL METHOD

The semiconfocal interferometer was chosen over the plane type because the latter presents more critical alignment problem and also because the diffraction losses are considerably less in the semiconfocal interferometer.

* This section co-authored by J. J. Gallagher, R. E. Cupp and M. Lichtenstein

The plates (one flat and one curved) were designed such that the parameter $a^2/b\lambda \approx 1$ at 168 gc, where a is the radius of the plates, b is the radius of curvature of the curved plate, and λ the wavelength in the medium. For larger values of the ratio $a^2/b\lambda$, the field at the edge of the reflectors decreases thereby decreasing the losses. By limiting this parameter to a value of 1.0 or slightly less, the diffraction losses for the fundamental mode (TEM_{ooq}) are comparable to the reflection losses. Since Q is also limited by the reflection losses, little is gained by lowering the diffraction losses below the value obtained for a ratio $a^2/b\lambda \approx 1.0$. Since the diffraction losses for the next higher mode are an order of magnitude greater than the losses for the fundamental mode, some mode discrimination can be realized by such a limitation of the $a^2/b\lambda$ parameter. Although the ratio given above was calculated for a frequency of 168 gc, the interferometer had sufficient bandwidth to extend at least over the frequency region of 150 to 217 gc.

The confocal resonator uses two curved plates of the same radius of curvature with a separation equal to this radius. The semiconfocal resonator uses one curved plate and one flat plate; therefore, the plate separation is 1/2 the radius of curvature of the curved plate.

The condition of resonance for the TEM_{mnq} mode for the confocal resonator is given by [12]

$$\frac{4d}{\lambda} = 2q + (1+m+n),$$

where

$d = R =$ radius of curvature

$q =$ number of half-wavelengths between reflectors

$m, n = 0, 1, 2,$ represents the mode variations.

This equation reduces to $4d/\lambda = 2q + 1$ for the TEM_{ooq} mode, and the relation is valid for the semiconfocal resonator due to the equivalence of the confocal and semiconfocal cases.

The plates were machined out of brass and have a diameter of 1.5 inches, with an 8-inch radius of curvature for the curved plate. Since $R = 8$, the plate separation is 4 inches. The plates were polished and coated with aluminum by vacuum-deposition techniques.

The coupling into and out of the resonator was achieved by the direct waveguide method. Both the input and output waveguides (R-138/U) are located on the flat plate with a 3/16-inch center-to-center separation and located symmetrically about the center lines. To prevent loading the resonator too heavily, an iris was used over the waveguide with a hole smaller than the waveguide opening. This was achieved by counterboring the waveguide acceptance hole from the rear of the plate and leaving a 0.003-inch wall thickness at the surface; the waveguide is then butted against the iris. A 0.020-inch hole was found to be too small for good transmission. When the hole size was increased to 0.025 inch, a good transmission response was obtained. A transmission loss of about 20 db ± 3 db was measured for this type of coupling. Figure 2 illustrates the arrangement of the direct waveguide-iris coupling. The lathe bed carriage used to contain the plates and to vary the resonant frequencies is shown in Figure 3.

Frequency measurements were made on the observed lines by comparing the harmonics of a phase-locked X-band source with the fundamental sources covering the range of 50 to 75 gc. Signals in the 167 to 216 gc region were generated by using harmonic generators of the crossed-waveguide run-in type; the signals were detected by run-in crystal detectors. The entire experimental system is shown by block diagram in Figure 4.

B. EXPERIMENTAL RESULTS

The strong $H2S^{32}$ lines, corresponding to the $1_{-1} \rightarrow 1_1$ and $2_0 \rightarrow 2_2$ transitions at 168.7 gc and 216.7 gc respectively, were easily observed. The observation of these lines was expected since S^{32} has a natural concentration of 95 percent. The lines corresponding to the isotopic species, H_2S^{33} and H_2S^{34}, for the same transitions were observed by a video presentation. Table I lists the observed line frequencies and their calculated transition intensities. The natural concentrations are the following: $S^{32} = 95.1$ percent, $S^{33} = 0.74$ percent, and $S^{34} = 4.2$ percent. The H_2S^{33} lines at 168.3 gc and 215.5 gc are believed to be the weakest lines observed in a video presentation in the millimeter region.

Figure 5 is an oscilloscope pattern obtained for the H_2S^{32} line at 216.7 gc. As a general rule, small-cavity spectrometers tend to show saturation effects more readily than standard waveguide cells. However, since the region of interest was attained by using harmonics of klystrons operating from 55 to 72 gc, less power was available at the higher frequencies, and, because of the high signal-to-noise ratio, less power was required. Hence, power saturation effects were not noticable in the millimeter region. The power output from the harmonic generator was measured to be 0.5 milliwatt. The power measurement was made with a Melabs dry calorimeter at the output of the harmonic generator, which had a cutoff frequency of 115 gc. The fundamental power from the OKI klystron was measured to be approximately 150 milliwatts with a PRD dry calorimeter.

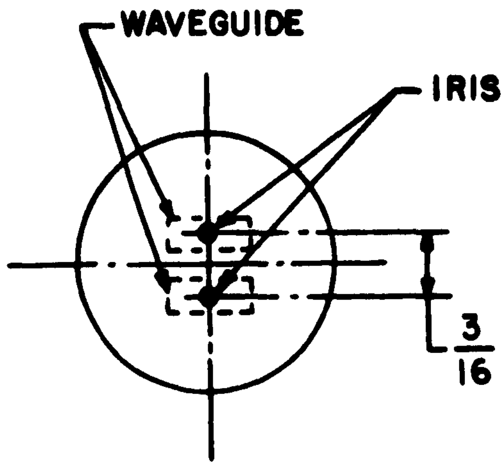

Figure 2. Waveguide-Iris Coupling Arrangement

TABLE I

Observed Line Frequencies and Transition Intensities for the Isotopic Species of H_2S

Transition	Line Frequency mc/sec	Intensity cm^{-1}
$1_{-1} \rightarrow 1_1$: H_2S^{32}	168,762.87	6.45×10^{-3}
$1_{-1} \rightarrow 1_1$: H_2S^{33}	168,319.10	1.60×10^{-5}
$1_{-1} \rightarrow 1_1$: H_2S^{34}	167,910.57	2.58×10^{-4}
$2_0 \rightarrow 2_2$: H_2S^{32}	216,710.46	1.28×10^{-2}
$2_0 \rightarrow 2_2$: H_2S^{33}	215,502.67	3.07×10^{-5}
$2_0 \rightarrow 2_2$: H_2S^{34}	214,377.00	5.12×10^{-4}

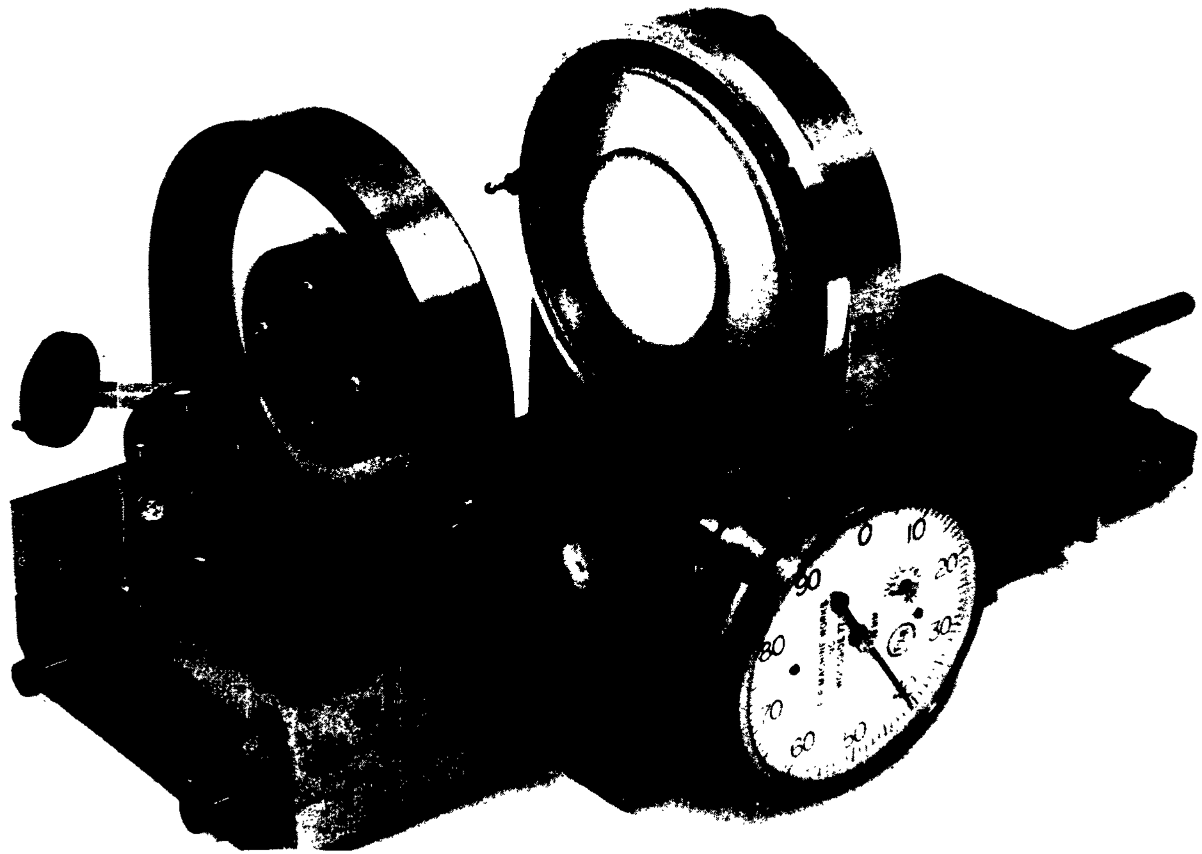

Figure 3. Semiconfocal Interferometer with Housing

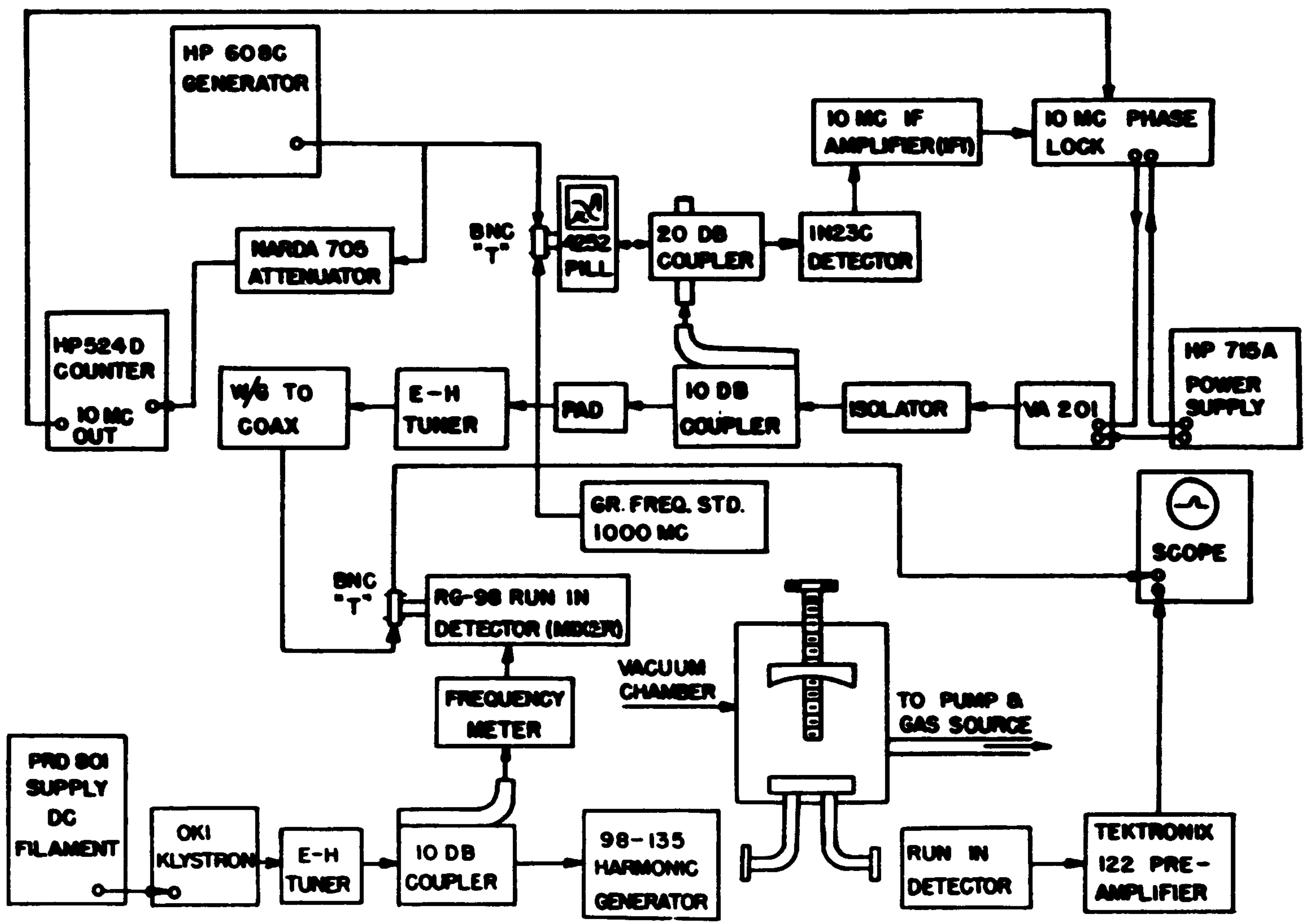

Figure 4. Experimental System

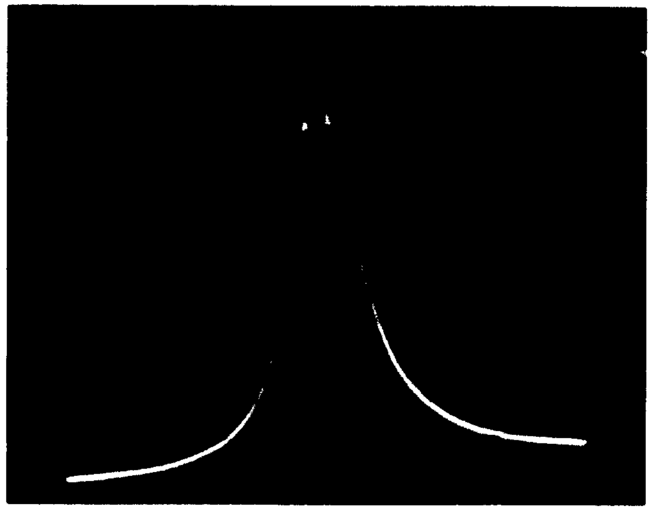

Figure 5. Oscilloscope Pattern of Resonant Cavity and H_2S^{32} Line at 216.7 gc

Figure 6 shows a comparison between the $1_{-1} \rightarrow 1_1$ H_2S^{34} line obtained in the semiconfocal resonator and the same line obtained in a waveguide absorption cell 14 inches long, using the same klystron and harmonic generator. A Q value of 56,000 was measured in the resonator at 167.9 gc, thus giving an equivalent absorption path length of 52 feet to the semiconfocal spectrometer. A Q value of 38,400 was measured at 215.5 gc. With the experimental arrangement shown in Figure 4, the Q values were calculated from the $\Delta\nu$ measurements, which were obtained by superimposing on the half-power points of the cavity resonance the beat from the sixth harmonic of the phase-locked X-band source with the fundamental of the OKI source.

Figure 7 shows the weak $1_{-1} \rightarrow 1_1$ line of H_2S^{33} with S^{33} in its natural concentration of 0.74 percent. Due to the interaction of the S^{33} nuclear quadrupole moment with the molecular electric field, a splitting of the rotational levels occurs and a multiplet structure results. Burrus and Gordy[10] have resolved the multiplet structure for the H_2S^{33} $(1_{-1} \rightarrow 1_1)$ line by a recorder tracing. The observed components shown in Figure 7 correspond to the $5/2 \rightarrow 5/2$ and $3/2 \rightarrow 1/2$ transitions which fall at 168,319.10 mc. (This is the same frequency, within the experimental error, as observed by Burrus and Gordy.[4]) The remainder of the components were too weak to be seen in the video presentation.

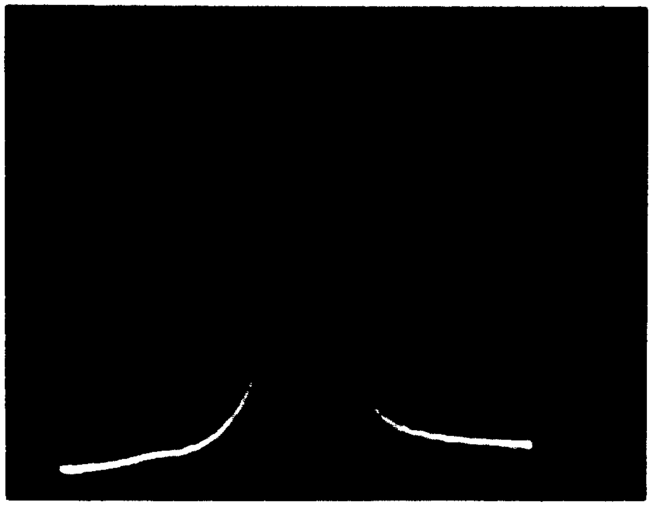

Figure 6a. Oscilloscope Pattern of Resonant Cavity and H_2S^{34} Line at 167.9 gc

Figure 6b. Oscilloscope Pattern of H_2S^{34} Line at 167.9 gc Obtained from Waveguide Absorption Cell

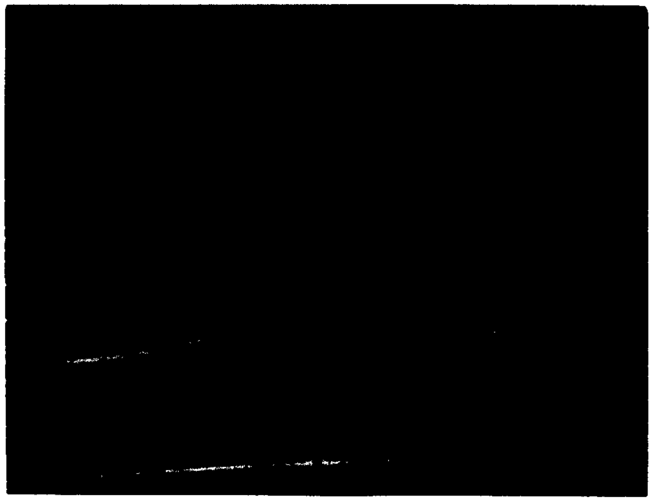

Figure 7. Oscilloscope Pattern of Resonant Cavity and H_2S^{33} Line at 168.3 gc

The high signal-to-noise ratio achieved in the small-volume resonator type of spectrometer is worth the slight additional difficulty of construction. The advantages of these spectrometers are especially important in the millimeter range where very little power is available. The small dimensions allow electric and magnetic fields to be applied for Stark and Zeeman studies. It is expected that resonance spectrometers will become increasingly more important as studies progress into the instrumentally hybrid region between one millimeter and 100 microns.

ACKNOWLEDGEMENT

The authors would like to thank Mr. J. W. Dees for design considerations of the interferometer; Mr. R. G. Strauch for his assistance in taking measurements; and Mr. C. E. Martin for the fabrication of the interferometer plates and vacuum housing.

IX. CONCLUSION

The molecular beam apparatus is now in operating condition and beam detector tests can be performed. Following the satisfactory operation of a beam detector, the electric resonance experiments will be performed. An ammonia maser has been used for stability tests of phase-locked oscillators. Arrangements are being made to observe maser oscillations for ammonia in a semiconfocal interferometer. An analysis of the hydrogen sulfide spectrum is being performed to determine the effects of distortion on the observed transitions and to predict unobserved transition frequencies.

A hydrogen sulfide maser is being assembled to observe oscillations at 168.7 gc. This maser will be used to test spectral purity of harmonically generated phase-locked signals. Absorption studies are being made on molecular beams to ascertain the optimum method of applying the signal to the beam.

A millimeter spectrometer, employing a Fabry-Perot interferometer, has demonstrated high sensitivity in the region from 160 to 220 gc.

X. PROGRAM FOR NEXT QUARTER

The beam detector studies will be continued during the next period, and the initial electric resonance experiments will be performed. The ammonia maser will be operated in a semiconfocal interferometer, and attempts will be made to observe a rotation-inversion transition in the resonator. The work on the hydrogen sulfide maser will continue in an attempt to obtain oscillations at 168.7 gc. The hydrogen sulfide spectroscopy will be reported with an analysis given of the existing data. The line width studies on the molecular beam will continue; this latter work is extremely important for the frequency control system since the radiation technique appears as a severely limiting factor.

KEY PERSONNEL

J. J. GALLAGHER

J. J. Gallagher is a senior research scientist in the Research Division's Physical Sciences Laboratories at Martin Orlando. He is responsible for the U.S. Army Signal Corps' "Excitation and Detection Techniques for Millimeter Wave Transitions" contract, DA-36-039-SC-90753. His field of research in the field of molecular amplification includes paramagnetic resonance, optical pumping, microwave spectroscopy and millimeter gas masers. He is also experienced in solid state physics and microwave spectroscopy.

Mr. Gallagher obtained his BS degree in physics in 1948 from Siena College, his MA in physics from Columbia University in 1952 and has completed graduate studies at Renssalaer Polytechnic Institute, New York University and John Hopkins University.

He has authored or co-authored thirteen technical papers and is a member of the American Physical Society.

R. G. STRAUCH

R. G. Strauch is an engineer in the Research Division's Physical Sciences Laboratories at Martin Orlando. He is presently researching in the fields of harmonic generation and phase locking klystrons. He has also worked on the development of a rubidium vapor atomic frequency standard and a travelling wave maser.

He received his BEE degree in Electrical Engineering from the University of Florida in 1959 and has completed course work for an MSEE degree at the University of Pennsylvania. He is a member of the IEEE.

R. E. CUPP

R. E. Cupp is an engineering associate engaged in the areas of waveguide components, lasers, millimeter harmonic generation and detection. He attended Indiana Tech and is a graduate of the U.S. Navy Electronics School. He is a member of the PGMTT of the IEEE.

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